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GEOBOTANICAL REMOTE SENSING FOR DETERMINATION OF AGGREGATE SOURCE MATERIAL

ABSTRACT A research study employing remote sensing techniques was initiated in 1987 by the Naval Civil Engineering Laboratory (NCEL) to determine if vegetation could be used to discriminate parent materials for suitability as aggregate source material. Two test sites representing potential alluvial and residual source areas were selected in a semiarid region of Central California.

Methods developed for the study included field observations of vegetation characteristics associated with the two parent material types along with the analysis of Thematic Mapper Simulator data flown over the test sites on April 24, 1987. Image processing techniques included band composites, band ratios, principal components analysis, and linear recombination. The most useful images were those composites that included bands from two of the techniques (i.e, a Perpendicular Vegetation Index (PVI) band combined with principal components bands). The image processing demarcated species compositional differences which characterized the shale site. It also revealed differences in the alluvial site caused by moisture stress as a result of aggregate size and sorting. The alluvium best suited for aggregate source material was better drained and thus contributed to the premature dessication of the overlying annual vegetation.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

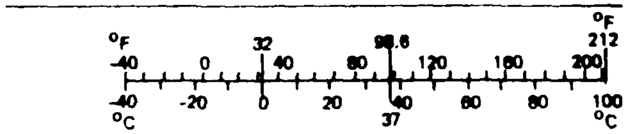
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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A research study employing remote sensing techniques was initiated in 1987 by the Naval Civil Engineering Laboratory (NCEL) to determine if vegetation could be used to discriminate parent materials for suitability as aggregate source material. Two test sites representing potential alluvial and residual source areas were selected in a semiarid region of Central California.

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Methods developed for the study included field observations of vegetation characteristics associated with the two parent material types along with the analysis of Thematic Mapper Simulator data flown over the test sites on April 24, 1987. Image processing techniques included band composites, band ratios, principal components analysis, and linear recombination. The most useful images were those composites that included bands from two of the techniques (i.e., a Perpendicular Vegetation Index (PVI) band combined with principal components bands). Multispectral Images, Geobotanical Mapping (AU)

CONTENTS

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INTRODUCTION

Aggregate source material suitable for facility and roadbed construction is often a very limited and highly valuable resource. The location of suitable source material is crucial to construction operations once facility requirements are established. Finding material for use in construction requires accurate, up-to-date information on the location, type, and areal extent of the aggregate-bearing units. Existing reconnaissance methods are often too slow and labor intensive.

The Naval Civil Engineering Laboratory (NCEL) has been exploring potentially faster, more accurate methods of construction material location using remote sensing techniques. The application of airborne and spaceborne remote sensing to terrain information requirements has proved attractive because of the rapid processing time and extensive spatial coverage associated with remotely gathered imagery. Source material identification may be improved by the remote sensing of vegetation associated with the material, particularly in areas of high vegetative cover.

This report documents the results of NCEL's research into the effectiveness of traditional and remote sensing techniques for locating potential construction source material. A strategy for identifying two sources of aggregate material using geobotanical discrimination involving airborne thematic mapper imagery was developed. Image processing was used to determine optimal techniques for discriminating these materials from less desirable and/or less economic units.

Traditional methods of construction material location often rely on local knowledge of potential aggregate source materials or on outdated, inaccurate maps of the region under consideration. These methods, which often entail extensive field surveys, core samplings, and mapping, are quite expensive, time consuming, and labor intensive. Yet, with the greatly increased need for aggregate in current construction activities, new sources must be sought and new methods for accurately and rapidly assessing their extent and location must be developed. Traditional remote sensing techniques offer promise in mapping aggregate source materials in the absence of thick vegetation canopies. When vegetation masks the underlying parent material, techniques must be developed that take advantage of the unique physical relationship between the vegetation and the material it is growing on.

BACKGROUND

The use of vegetation to identify parent material characteristics is based on the assumption that one or more factors related to the parent material will affect one or more vegetation factors. The use of geobotany in geological investigations is certainly not new. Brooks (1983) has reviewed a number of case studies. The use of remote sensing in

these studies is predicated on the assumption that a vegetation response to the underlying geochemical/geophysical condition may be discriminated in a remote sensing strategy. The primary vegetation responses to these conditions that may be discriminated through the use of remote sensing include taxonomic, structural, and spectral responses (Mouat, 1982). Plant indicators (as an example of taxonomic responses) may be highly reliable keys to differences in parent materials but are rarely discriminable by remote sensing techniques. Differences in plant assemblages, however, frequently have unique spectral responses. Structural responses including chlorosis, stunting, density, premature or retarded senescence, and flowering characteristics are often associated with changes in parent material. These responses can frequently be discriminable through a remote sensing strategy. Vegetation may also have structural responses that have peculiar spectral characteristics. In previous research, these responses have sometimes been the result of photosynthesis characteristics being affected by heavy metals in the soil (e.g., Horler et al., 1983, and Labovitz et al., 1983). In other cases, vegetation may be stressed by differential moisture availability related to parent material characteristics (Cibula, 1982).

It is known that vegetation density and compositional differences may be directly discriminable by remote sensing techniques such as color infrared aerial photography and the Landsat MSS and TM (e.g. McDaniel and Haas, 1982; Milton, 1983; Ripple, 1986; Segal, 1983). If the relationships between these remotely sensed structural characteristics of vegetation and aggregate-bearing source materials can be determined, then an operational strategy for source material identification will have been developed.

STUDY AREA

A study area was developed within the Ft. Hunter Liggett Reservation of West Central California (Figure 1). The area is characterized by known sources of both residual and nonresidual aggregate material suitable for construction of light and heavy use roadways. Although some of this material has already been quarried, most lies undisturbed and is covered by the native vegetation, thus providing a suitable environment for the determination of the geobotanical relationships between this vegetation and the associated parent material.

The Ft. Hunter Liggett Reservation covers an area of 261 square miles. In spite of the large size of the reservation, adequate aggregate sources have been restricted to isolated areas along riparian zones and in the calcareous Monterey Shale. While typical shale makes a poor aggregate source because of poor shear strength (especially when wet), the Miocene Monterey Shale has a calcareous facies which provides an adequate aggregate for light use road base material (Barnes, 1987). By contrast, the alluvial source for aggregate provides material suitable for heavier uses (runways, large tracked and wheeled vehicle routes).

The semiarid to Mediterranean climate of the reservation supports a varied vegetation ranging from annual grassland and a scattered oak-covered grassland to several types of chaparral, oak woodland, mixed

broadleaf-conifer forest, and conifer forest. The distribution of this vegetation is modified primarily by elevation, microclimate, fire history, topography (especially aspect), and parent material.

METHODOLOGY

A geobotanical strategy is being suggested that attempts to separate the parent material-vegetation relationship component from other surface cover relationships. The parent material of interest is that which relates to aggregate-bearing source material.

In the strategy of this investigation, remote sensing is used to discriminate those vegetation characteristics that are associated with the aggregate-bearing source material. Specifically, spectral data transformations including band ratios, principal components analysis and linear recombinations that may be highly correlated with the vegetation parameters, were explored as potential tools for exploiting the vegetation-parent material relationships.

The sensing system selected was the twelve-channel Daedalus AADS1268 multispectral scanner or Thematic Mapper Simulator (TMS). Seven of the TMS bands were used in this investigation. They include (with their Thematic Mapper equivalents):

Thematic Mapper Simulator (TMS) Bands	Thematic Mapper (TM) Bands	Wavelength (micrometer)
2	1	0.45 - 0.52
3	2	0.52 - 0.60
5	3	0.63 - 0.69
7	4	0.76 - 0.90
9	5	1.55 - 1.75
10	7	2.08 - 2.35
12	6	10.40 - 12.50

The selection of an appropriate range of image acquisition dates was essential. It was felt that the best season to take advantage of plant phenological responses was after peak green-up and during the period of plant brown-off (or the onset of senescence) for both the grass vegetation types and the chaparral (characterized by a high shrub cover). In Central California, the winter precipitation is accompanied by a rapid green-up, especially of the annual grasses and forbs. Perennial species, including shrubs, green-up at a later date. The onset of senescence is also different for both classes of vegetation, with the annual grasses senescing prior to the shrubs. In considering these differences in phenology, a period of image acquisition was established that would occur following the onset of senescence of the grasses and into the green-up and early senescence of the shrubs. Such a window is depicted in Figure 2. In 1987, that window occurred approximately from the end of March to the beginning of May.

A field sampling strategy was designed and implemented to identify the primary aggregate sources within the reservation and to characterize vegetation and parent materials within each of the major aggregate types.

The image processing system utilized was a Hewlett Packard (HP) Interactive Digital Image Manipulation System (IDIMS) residing at National Aeronautics and Space Administration (NASA) Ames Research Center.

Data Acquisition and Preprocessing

The data were acquired using a Daedalus AADS1268 Airborne Thematic Mapper Simulator (TMS) mounted in a NASA U-2C aircraft. The data mission was flown on April 24, 1987 at an altitude of 20,000 meters giving an equivalent ground resolution of 26 meters in all spectral bands. The data were recorded in flight on a high density digital recorder, and then converted by a ground-based decommutation system into computer compatible tapes.

The initial processing included geometric corrections to remove overscan and panoramic distortion. The overscan correction involves the removal of redundant scanlines. The panoramic distortion is eliminated by replicating pixels towards the edges of the image based on the secant of the pixel view angle. This converts uniform angular sample spacing into uniform ground sample spacing in the image, and effectively "flattens" the image projection. With a relatively narrow field of view on this system of 42.5°, the panoramic distortion is not severe; the image width being increased from 716 to 750 pixels.

Field Analysis

A field sampling strategy was designed to identify primary aggregate sources within the reservation and to characterize vegetation and parent materials within each of the major aggregate types. A local sand and gravel operator provided considerable advice on the former task (Barnes, 1987). Field transects were randomly selected from within the two major aggregate sources at the two test sites. Detailed vegetation, soils, and geologic information was gathered along the transects. This information was analyzed to establish vegetation geological/aggregate relationships. The transect information was also subsequently used during the image analysis phase.

Image Processing and Analysis

Image processing techniques were conducted in a manner that would accentuate differences between potential source aggregate and surrounding material. As such, the standard band composites (TMS 5, 3, 2 and TMS 7, 5, 3, both in Red, Green, Blue) were constructed for both the alluvial site and the shale site. Thermal composites combining the TMS 12, 7, 2 bands were attempted. Band ratios and composites of these ratios were constructed.

Principal components analysis was applied to the data set. It has been shown that the image data contained within the TMS and Thematic Mapper (TM) configuration are highly correlated between bands (Townshend, 1984). For example, while the digital values of vegetation in TMS 5 decrease with increasing photosynthetic activity, they increase in TMS 7, a near infrared band. Principal components analysis is a statistical

technique that derives uncorrelated linearly transformed components from the original data set. The technique transforms the data such that scene variance is maximized on the first transformation axis. Subsequent components are, by definition, orthogonal to the first, and maximize the residual variance of the remainder of the data set. Principal components analysis tends to preserve the total variance in the transformation while minimizing the mean square errors. Usually, variance due to scene characteristics is emphasized in the earlier axes (or principal components), while the smaller variance due to noise tends to be contained in the lower components. The scene albedo is often represented in the first principal component, while the second is related to vegetation. The transformation can be divided into three computational steps (Richards, 1986):

1. Derivation of the variance-covariance matrix
2. Computation of the eigenvectors
3. Linear transformation of the data set

Two six-banded principal components images were created from the TMS data set, one for the alluvial test site and one for the calcareous shale site. The six TMS input channels utilized in the principal components transformation were TMS 2, 3, 5, 7, 9, and 10.

This project also involved the use of a relatively new image processing technique known as a baseline technique or a linear recombination (LRC) of input data (see Mouat et al., 1986). Baseline-based indices involve the assessment of a background condition for any two channels designated by the analyst and the subsequent plotting of remaining values (or pixels) deviating from this background condition. The background condition is represented by a baseline in the two-channel digital value (DN) space. The deviation is attributed to spectral absorption measured as Euclidean distance in the DN space. The direct measurement of absorption in one band relative to another results in a more quantitative determination of surface materials than with the ratio technique. The LRC technique was used to create a Perpendicular Vegetation Index (PVI) band. The PVI index employs the red and near infrared bands to create an image that minimizes the influence of rock-soil spectral variation while yielding information about the phenological status of the vegetation canopy. This PVI band was combined with two of the generated principal component (PC) bands in an attempt to discriminate differences in vegetation spectra over different alluvium.

All of the processed images were contrast enhanced using a linear stretch technique. The grey scale was reversed in the enhancement of principal component 3 (or PC3) used in composites for the shale and alluvial sites. This resulted in an improvement of the discrimination of the potential source aggregate from the surrounding material for both sites.

RESULTS AND DISCUSSION

Image Processing

An examination of the aerial photography and the TMS imagery showed that both potential aggregate sources are discriminable. Surprisingly, the color infrared photography, while having higher spatial resolution, was not as useful as the standard TMS band composites for discriminating the differences in the vegetation associated with the two different aggregate source materials. This is probably a result of the ability to digitally enhance the TMS bands.

The simple band composite employing the thermal, a near infrared, and the blue channels (TMS 12, 7, 2) was successful in discriminating the coarse alluvial deposits (Figure 3). It is speculated that the coarser material loses moisture more rapidly, resulting in a faster brown-off of the vegetation canopy. This condition produces greater brightness temperatures within the coarse alluvium and thus contributes significantly to the red tone (from the thermal band). The area of coarser alluvium is identified with an arrow. The finer and medium-textured alluvium appears as yellow, with silt and clay alluvial admixtures represented in green owing to greater reflectance in the near IR band.

The TMS 12, 7, 2 band composite for the shale site also discriminated the Monterey Shale from the surrounding lithologies (Figure 4). The brightness temperatures of the chaparral covering the Monterey Shale appeared warmer than the vegetation on the adjacent metasedimentary and granitic units, thus creating a distinct red tone in the center of the image. The white shades mixed in with this red tone, however, may be attributed to the thin chaparral density and exposed parent material within the unit, creating high DN values in all three of the input bands. This in itself may be a geobotanical indicator since the sparse chaparral canopy is probably attributable to the close proximity of the shale bedrock to the surface and the absence of a well defined soil profile.

The six-band principal component products were quite useful in discriminating the aggregate-bearing source material. For this paper, eigenstructures were extracted for each of the study sites. Table 1 is the eigenstructure for the Monterey Shale site. From the covariance matrix, it is apparent that PC1 is loaded on the visible TMS channels as well as the middle infrared. This is consistent with the conception that the first principal component usually represents the albedo of the scene. The loadings are attributable to high reflectance values in the green and red bands, which result from the presence of bare rock and browning annual grasses. The increase in mid IR reflectance is due to reduced moisture content in the leaf structure. Principal component 2 is heavily loaded on the near infrared band (TMS 7), probably due to the predominantly vegetated landscape. Principal component 3, like PC1, is loaded on the visible bands, specifically green and red. This is also probably attributable to extensive browning of the grasses as well as exposed bed rock under sparse vegetation canopies. The first three components of this analysis account for about 99 percent of the total variance in the image. The PC 3, 2, 1 (RGB) combination proved the most valuable in discriminating the Monterey Shale unit from surrounding rock strata (Figure 5). The chamise-dominated chaparral canopy overlying the shale,

with a relatively low near IR reflectance, high mid IR reflectance, and high reflectance in the visible channels, contributes significantly to the first principal component and thus appears blue on the imagery (see arrow on Figure 5). It appears to be well separated from the surrounding vegetation species.

The eigenstructure for the alluvial site (Table 2) was very similar to that of the shale site. Loading relationships were relatively the same, with an even stronger contribution to PC1 from the green and red visible TMS bands. This is attributable to the greater overall scene albedo found in the alluvial scene, most likely caused by the wide, exposed channels of the San Antonio River and the existing construction site in the center of the image. Total percent variance for this analysis, like that for the shale site, was approximately 98 percent. PC-only composites, however, did not prove as useful for the alluvial site in discriminating the coarser aggregate-bearing material. Instead, the combination of PC2, PVI, and PC3 (reverse stretch) provided the best discrimination of the coarser alluvium (Figure 6). The higher near IR reflecting agricultural fields and fine to medium-textured alluvial areas appear yellow due to the combined affect of the PC2 and PVI bands. The coarser alluvial areas, because of their lower near IR reflectance and high reflectance in the visible bands, contribute to the third PC and thus appear as a faded blue in the imagery (see arrows on Figure 6). The PC2-TMS 7/5 ratio-PC3 composite was also constructed for the alluvial study area but did not prove as useful as the PC-PVI composite, perhaps because the 7/5 ratio did not minimize the influence of rock-soil spectral variation as well as the PVI.

Field Results

Extensive field work revealed two kinds of relationships between vegetation and terrain features related to aggregate: the first results from differential moisture characteristics of aggregate source material, and the second is the vegetation that grows upon potential aggregate source material.

The differential moisture characteristics of potential aggregate source material versus nonaggregate source material was prominent only within alluvium. It appears from analysis of the field data that the primary aggregate material occurring within the San Antonio River floodplain and associated terraces consists of gravel and cobble-sized material between 2 and 10 cm in diameter. Finer, sand-sized material is not as desirable, particularly at Ft. Hunter Liggett where the primary use of aggregate is for heavy and light use road construction (Barnes, 1987). The gravel and cobble occurs within older Pleistocene alluvial terraces. Particle size appears to increase near the edges of the older terraces although pockets of coarser material may occur within these terraces. The remainder of the older terrace deposits contains considerably less coarse material and typically has a much greater admixture of silt and clay. The latter alluvium retains moisture longer while the alluvium containing the more economic deposits loses moisture to infiltration and evapotranspiration more rapidly. As a result, the annual grass and forb vegetation types that comprise the alluvial terraces senesce more rapidly on the coarser (and more economic) material than on the finer material.

The resulting pattern of differential senescing is most apparent when the vegetation is still growing, but it is also apparent long after the vegetation is completely brown. A post-flight field analysis trip was made to the study area June 28-29, 1987, to verify the image results with field data. A number of features on the PC2-PVI-PC3 image were found to correspond closely with the field characteristics. The image and field data were used to derive Figure 7, a map of the spatial distribution of alluvial and other lithologic units in the study area. The coarse alluvium (Qac) units are well drained with relatively large particles, while the medium-textured alluvium (Qam) and fine alluvium (Qaf) units are characterized by smaller cobble and less infiltration capacity.

Differences in vegetation composition involving different parent materials were determined to be of significant importance in differentiating the potential aggregate source material involving Monterey Shale. As stated previously, Monterey Shale, which has a pronounced calcareous component, was found to be the best residual rock type for aggregate source material within the study area. It is probable that a combination of the calcium carbonate itself as well as the added induration of the near surface environment results in the unique character of the vegetation growing upon that type of Monterey Shale. The primary vegetation type growing on this rock type is chamise-dominated chaparral. This pattern holds true even for areas that have experienced recent fires. In those areas, the vegetation composition may be almost pure chamise (Adenostoma fasciculatum), while in the older vegetated areas, the chaparral has a considerable component of other chaparral shrub species including manzanita (Arctostaphylos sp.), scrub oak (Quercus dumosa), and deerbrush (Ceanothus sp.).

CONCLUSIONS

In this report, an image processing strategy involving airborne thematic mapper imagery to analyze alluvial and shale lithologies successfully identified a number of aggregate-bearing units within the study area. Image processing techniques attempted included band composites, band ratios, principal components analysis, and linear recombination. The most useful techniques included thermal composites of TMS bands 12, 7 and 2, principal component composites, and the construction of a composite using bands from two techniques; the PC2-PVI-PC3 composite. The image processing demarcated the species compositional differences that characterized the shale site. It also revealed differences in the alluvial site that had not been determined by initial field work. Those differences were caused by moisture stress as a result of aggregate size and sorting within the alluvium. The alluvium best suited for aggregate source material was better drained and, hence, caused the overlying annual vegetation to dessicate prematurely.

It is felt that the techniques developed in this project can be used for aggregate and other nonmetallic exploration over a much larger geographic region. However, it must be stressed that for each application, the study areas are unique and must be analyzed individually. The success found in detecting subtle changes in vegetation phenology due to

moisture stress may hold promise for the application of these techniques to soil moisture determination. Future work, however, should be conducted to determine if the image processing techniques utilized at Ft. Hunter Liggett can be applied to extremely different climatic and physiographic regions of the world, such as arctic regions or tropical areas. The same techniques would probably not be as successful over tundra or rainforests; new methods may have to be developed that utilize different spectral bands and/or processing algorithms.

REFERENCES

Barnes, William (1987). Personal communication, Ft. Hunter Liggett, CA, Apr 1987.

Brooks, R. R. (1983). Biological methods of prospecting for minerals. John Wiley and Sons, New York, NY, 322 p, 1983.

Cibula, W. G. (1982). Utilization of Landsat multispectral data in geobotanical investigations: The location of ironstone gravel in the Sam Houston National Forest. NASA Earth Resources Laboratory Report 199, National Space Technology Laboratories, NSTL Station, MS, 1982.

Horler, D. N. H., Dockray, M., and Barber, J. (1983). " The red edge of plant leaf reflectance", International Journal of Remote Sensing, vol 4, 1983, pp 273-288.

Labovitz, M. L., Masuoka, E. J., Bell, R., Siegrist, A. W., and Nelson, R. F. (1983). "The application of remote sensing to geobotanical exploration for metal sulfides-results from the 1980 field season at Mineral, Virginia," Economic Geology, vol 78, 1983, pp 750-760.

McDaniel, K. C. and Haas, R. H. (1982). "Assessing mesquite-grass vegetation condition from Landsat," Photogrammetric Engineering and Remote Sensing, vol 48, 1982, pp 441-450.

Milton, N. M. (1983). "Use of reflectance spectra of native plant species for interpreting airborne multispectral scanner data in the East Tintic Mountains, Utah," Economic Geology, vol 78, 1983, pp 761-769.

Mouat, D. A. (1982). "The response of vegetation to geochemical conditions," in Proceedings, International Symposium on Remote Sensing of Environment, Second Thematic Conference: Remote Sensing for Exploration Geology, ERIM, Ft. Worth, TX, 1982, pp 75-84.

Mouat, D. A., Myers, J. S., and Miller, N. M. (1986). "An integrated approach to the use of Landsat TM data for gold exploration in West Central Nevada," in Proceedings, International Symposium on Remote Sensing of Environment, Fifth Thematic Conference: Remote Sensing for Exploration Geology, ERIM, Reno, NV, 1986, pp 615-626.

Richards, J. A. (1986). Remote sensing digital image analysis. Springer-Verlag, Berlin, 1986.

Ripple, W. J. (1986). "Spectral reflectance relationships to leaf water stress," Photogrammetric Engineering and Remote Sensing, vol 52, No. 10, 1986, pp 1669-1675.

Segal, D. B. (1983). "Use of Landsat multispectral scanner data for definition of limonitic exposures in heavily vegetated areas," Economic Geology, vol 78, 1983, pp 711-722.

Townshend, J. R. (1984). "Agricultural land-cover discrimination using thematic mapper spectral bands," International Journal of Remote Sensing, vol 5, No. 4, 1984, pp 681-698.

U.S. Geological Survey (1971). Geologic map of the Bryson 15' Quadrangle, California. U.S. Geological Survey Open-File Map 71-87, 1971.

Table 1. Eigenstructure of Monterey Shale Site

TMS Bands	Components of Covariance Matrix					
	1	2	3	4	5	6
2	0.22	-0.03	0.34	-0.35	-0.59	0.60
3	0.32	0.00	0.46	-0.35	-0.15	-0.73
5	0.39	0.22	0.32	-0.19	0.75	0.31
7	0.16	0.92	-0.06	0.27	-0.23	-0.04
9	0.50	-0.02	-0.74	-0.44	-0.02	-0.04
10	0.65	-0.33	0.05	0.67	-0.10	0.01
Eigenvalues	624.2	52.2	22.7	7.8	1.7	0.53
% Variance	88.0	7.4	3.2	1.1	0.25	0.07

Table 2. Eigenstructure of Alluvial Site

TMS Bands	Components of Covariance Matrix					
	1	2	3	4	5	6
2	0.29	-0.21	0.49	-0.75	0.23	0.09
3	0.64	-0.28	-0.26	-0.05	-0.66	0.00
5	0.50	0.02	0.55	0.63	0.21	0.03
7	0.16	0.90	0.17	-0.15	-0.29	0.18
9	0.38	0.25	-0.33	-0.10	0.39	-0.72
10	0.31	0.05	-0.49	0.01	0.47	0.66
Eigenvalues	648.6	54.1	24.3	10.5	6.4	1.0
% Variance	87.0	7.3	3.3	1.4	0.86	0.14

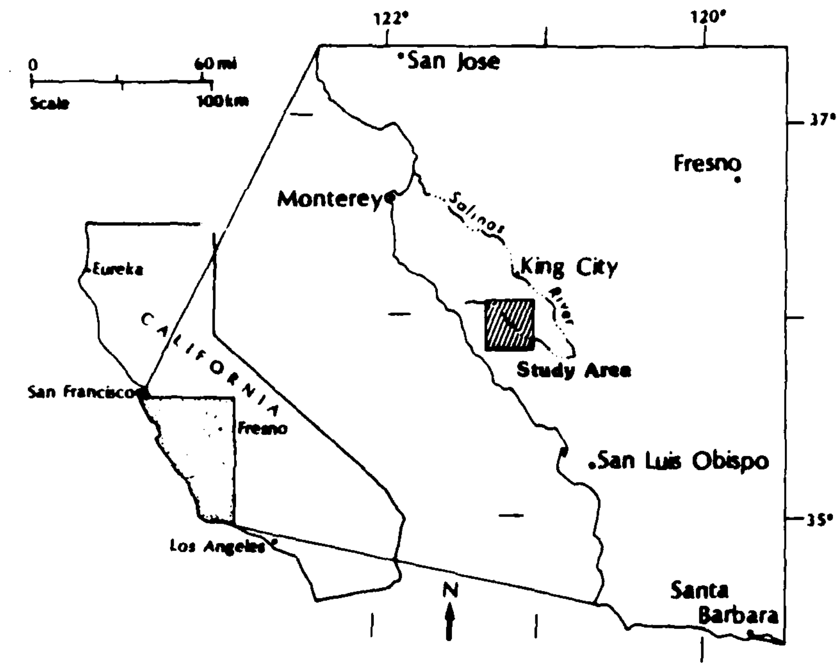


Figure 1. Location of study area.

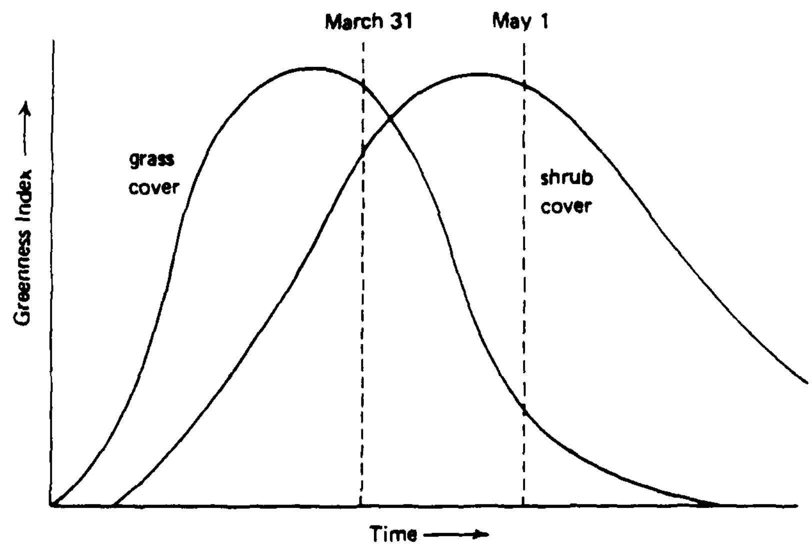


Figure 2. Conceptual representation of the phenological status of grass-dominated and shrub-dominated vegetation types in the study area. Dates are approximate for 1987.

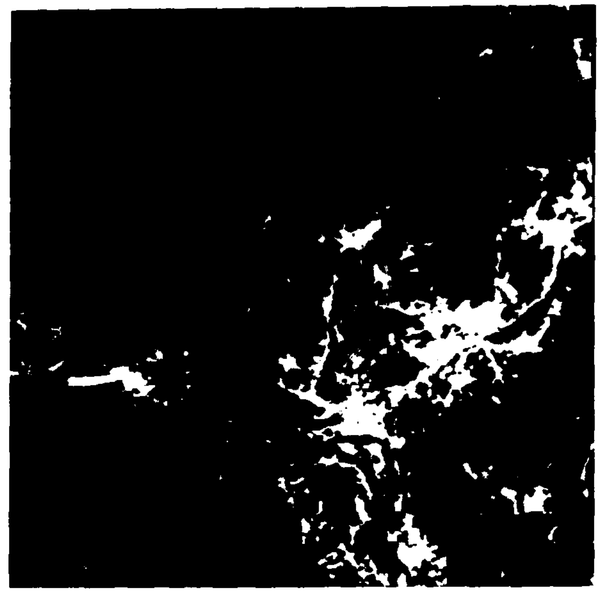
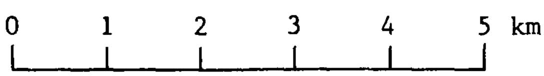


Figure 3. TMS 12, 7, 2 (RGB) - Alluvial site.

Figure 4. TMS 12, 7, 2 (RGB) - Shale site.

Scale for all Figures:



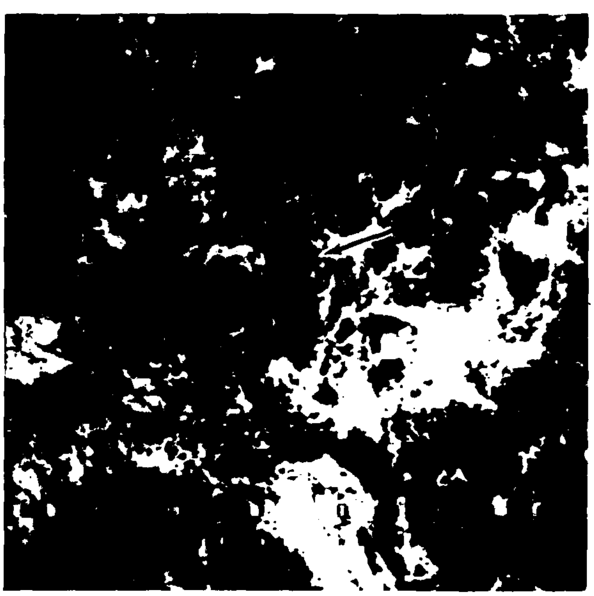
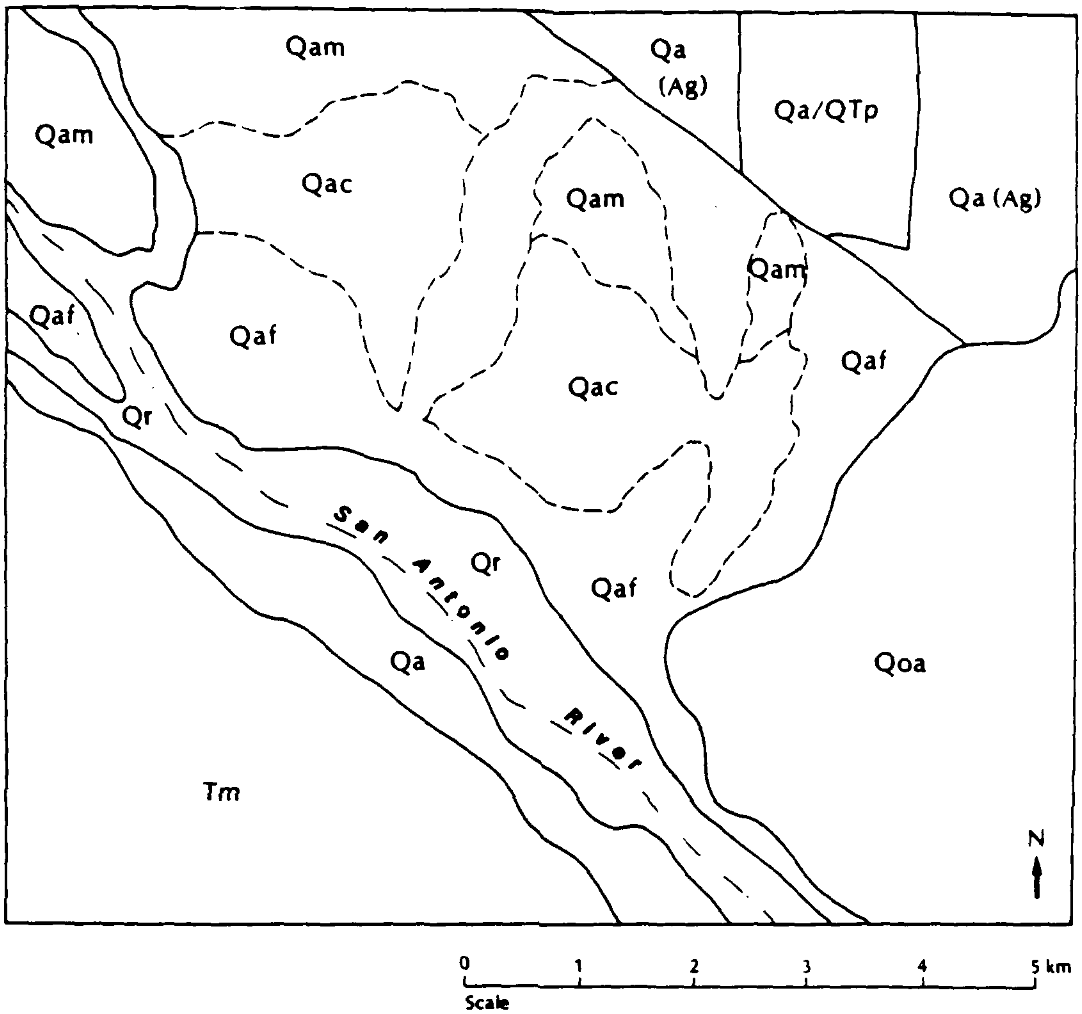


Figure 5. PC3-PC2-PC1 (PC3 reverse stretch) Shale site.

Figure 6. PC2-PVI-PC3 (PC3 reverse stretch) - Alluvial site.



Legend

Ag	- Agriculture	Qa	- undifferentiated late Pleistocene alluvium
Q	- Quaternary	Qaf	- fine-textured alluvium
T	- Tertiary	Qam	- medium-textured alluvium
Qr	- recent alluvium	Qac	- coarse-textured alluvium
Tm	- Montery Shale		
Qoa	- older Pleistocene alluvium		
QTp	- Paso Robles formation (valley sediments)		

Figure 7. Surficial geology of the alluvial site (Interpreted from the PC2-PVI-PC3 (reverse stretch) image. Names of some units obtained from USGS, 1971.)

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